

A search for binary black hole candidates from the VLBI images of AGNs

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Abstract. We have searched the core-jets pairs in the VLBI scales (<1 kpc), from several VLBI catalogues, and find out 5 possible binary black hole (BBH) candidates. We present the search result and analyze the candidates preliminarily, and further study with multi-band VLBI observation and optical line investigation would be carried out in the future.

Key words: Binary black hole – radio continuum: jets pair

1. Introduction

In the co-evolution scenario of galaxies and their supermassive black holes, galaxy-galaxy mergers would end up with forming binary black holes (BBHs). Close binary black holes are important in astrophysics and also they would be the strongest gravitational wave sources in the universe. As the binary orbiting black holes give off gravitational waves, their orbit decays and the orbital period decreases. This stage is called binary black hole inspiral. Galaxy-galaxy merging systems are mostly found in optical and X-ray images. In radio, it is less efficient in identifying active nuclei pairs of merging systems, because most of them are radio-quiet. However, an advantage in radio is the VLBI which can resolve the close binary system at pc scale, if the nuclei are radio loud. In >1 kpc scales, the frequency of double nuclei of merging galaxies was estimated to be $\sim 1\%$ in the optical samples (Wang, et al. 2009; Liu et al. 2013). Assuming 10% of the AGNs are radio loud in optical sample, the detection rate of twin-jets pairs in radio reduces to $\sim 0.1\%$ in the optical selected sample. A similar fraction ($\sim 0.1\%$) is expected in the radio selected sample for both the double nuclei being radio loud.

The VLBI can image the radio jets of AGN at pc scales, providing an unprecedented high resolution probe to close binary black holes. Even if the

detection rate as low as $\sim 0.1\%$, with up-to-date large VLBI databases one could still be able to find out close binary radio jets pairs launched from binary black holes. Such a VLBI search for close binary radio cores done from the geodetic VLBI database, found only one binary cores system from 3114 sources (Burke-Spolaor 2011). The detection rate seems less than that estimated above by a factor of 3. We have searched the core-jets pairs from astrophysical databases, and present the preliminary results in this paper.

2. Radio jets pairs as the BBH signatures

It is more efficient to find binary AGNs in <10 kpc than in 10 -100 kpc scales, suggesting that simultaneous fuelling of both black holes is more common as the binary orbit decays through shorter spacings (Smith et al. 2010). If both nuclei are radio loud, in <1 kpc scales, the VLBI is the most efficient probe to find the compact inspiral cores. However, in a relatively small sample of AGNs with double-peaked optical emission lines, Tingay & Wayth (2011) have not detected compact double cores with the VLBA. Burke-Spolaor (2011) searched for flat spectrum double cores in large geodetic VLBI database, and find only one, i.e. B0402+379. The apparent deficit of double cores at the small spacings is not clear, a reason may be that one of double cores could be obscured/absorbed or very weak. Independent searches with different strategies from different samples are needed to confirm whether the deficit is real.

Our strategy of searching for BBH candidates is looking for not only flat spectrum double cores, but also twin-jets pair. Double twin-jets are found more frequently in >1 kpc scales than in the VLBI scale, e.g. the 19 X-shaped radio sources and 100 X-shaped candidates (Cheung, 2007), and the double-double radio galaxies (e.g. Liu et al. 2003), whereas their radio cores are often absent or weak probably due to large viewing angles. The VLBI databases in our searches are the MOJAVE database (Lister et al. 2009), the Pearson-Readhead survey and the first Caltech-Jodrell Bank survey (PR+CJ1, e.g. Xu et al. 1995), the second Caltech-Jodrell Bank survey (CJ2, e.g. Henstock et al. 1995), the CJF sample (Britzen et al. 2007), the VLBApls sample (Fomalont et al. 2000), and the VIPS sample (Helmboldt et al. 2007). The resulted candidates from ~ 2000 sources are summarized in Table 1. We define a spectral index with $S \propto \nu^\alpha$.

3. Comments on individual BBH candidates

We find 6 possible BBH candidates from our intensive searches, they have shown features likely either double core-jets or a compact core plus a core-jet. We comment and analyze preliminarily these sources in the following.

B2 0402+379

This is a previously suggested supermassive BBH system which showing

Table 1. The 6 BBH candidates, the number in the last column are catalogues: 1–MOJAVE, 2–CJ1, 3–CJ2, 4–CJF, 5–VLBAp1s, 6–VIPS

Name	Other	Id	z	Cat
J0405+3803	B2 0402+379	G	0.055046	(4,5)
J1001+5540	4C55.19	G	0.003723	(6)
J1158+2450	PKS 1155+251	Q	0.201600	(1,5,6)
J1215+3448	B2 1213+350	Q	0.857000	(2,4,5,6)
J1632+3647	B2 1630+35			(6)
J2253+1608	3C454.3	Q	0.859000	(1,5)

a compact radio core and a nearby Compact Symmetric Object (Rodriguez et al. 2006). Two components of HI absorption lines were found, which are supporting the BBH model of the source (Morganti et al. 2009).

4C55.19 (J100157.93+554047.8)

The host is a nearly edge-on spiral galaxy NGC 3079 with a LINER nucleus, which is classified as a Seyfert 2 galaxy and a low luminosity AGN. The VIPS image at 5 GHz exhibits three compact components, the south-east one (A) and the northwest one (B) are consistent with the detections with global VLBI by Sawada-Satoh et al. (2000, SS hereafter). The third component in the northeast of the VIPS image has a position angle close to the minor axis of the galaxy, which may either relate to a fresh outflow, or might be a young supernova remnant, this component was not detected in SS. Mostly likely the component B is the core and A is a jet as suggested by SS, but the component A is more compact and brighter than B in the 5 GHz VIPS image, indicating a strong variability of the components compared with the 5 GHz image of Trotter et al. (1998). The jet is misaligned with the short axis of the galaxy, the radio ‘core’ is at about 0.5 pc west to the galactic nucleus according to Trotter et al. (1998), implying this radio core is probably a secondary core in a BBH system. Hagiwara et al. (2004) found two OH absorption components in the central region, but its relation to a possible BBH system needs further investigation.

PKS 1155+251 (SDSS J11584+2450)

The quasar is point like in both the NVSS and FIRST images, and shows a slightly extension along southeast-northwest with the VLA D-array (Tremblay et al. 2008) and they reclassified this source as a CSO, and discussed a possible shrinking of the source from new VLBA observations at 4.84, 8.34, and 15.13 GHz. However, the complex structure of the source was not fully explained with the CSO scenario, for the exotic diffuse emission towards the west which is perpendicular to the CSO jet axis. The 15 GHz images in Tremblay et al. (2008) and in the MOJAVE showed the southern

brightest component is quite compact, although its spectral index being steep as estimated from the 15 GHz and lower frequencies (but note that the compact component embedded in the jet/diffuse emission which may lead to an overestimate its flux densities at the lower frequencies), a spectral index between 15 and 43 GHz is vital to clarify its nature. The spectrum of the source total flux density shows a flat spectrum in <3 GHz in the NED, this flat spectrum is not consistent with a usual steep spectrum of CSO. Furthermore, there seems a jet in the west connected to the southern-end component. Therefore, possibly the southern-end component is a core. In this scenario, the source has two cores and jets. The diffuse emission in the west could be due to the precession of the binary system. We measured the separation between the two candidate cores with the MOJAVE data at three epochs 1995.4, 1999.5 and 2001.3, the resulted separation is within 3.38 ± 0.13 mas, in supporting the non-expansion between the central core component and the southern brightest component (Tremblay et al. 2008). Kellermann et al. (2004) also considered this complex source had two split jets. We keep the source as a possible BBH candidate for future VLBI monitoring and optical line study.

B2 1213+350 (SDSS J121555.60+344815.2)

The quasar shows a point like in the NVSS image, while has a short jet to northeast in the FIRST image. The VLBI images at 1.6 and 5 GHz from the CJ1 showed a strong hotspot-jet association in the northern and a compact component in the south. The 5 GHz VIPS image revealed a short jet from the southern ‘core’ candidate. Likely the southern one is the core and the northern part is the jet/hotspot. However, the northern feature seems being jetted to southeast and then the jet curved to northeast. The overall radio spectrum of the source is -0.35 (1.4 GHz to 30 GHz) from the NED. From our estimate, the spectral indices of both the northern bright component and the southern core are flat from the 2.3/8.4 GHz RRFID VLBI data and the 5 GHz VLBApls data, so an alternative scenario could be still possible that the northern part harbors a secondary core. We keep it as a BBH candidate for further observations and study in detail, high frequency VLBI observation at 43 GHz are very needed to classify this source.

B2 1630+35

No optical and high energy band information available for this source, the radio spectrum shows a peaked shape around 1 GHz – a GPS source (Marecki et al. 1999). Both the NVSS and FIRST images show unresolved. The 5 GHz VIPS image exhibits a northern compact component and southeastern core-jet like features. No VLBI images at other frequency are available for a spectral index estimate of the components. Multi-band high resolution VLBI observations should be able to classify the source.

3C454.3

This is a highly variable quasar through whole electromagnetic spectrum. Total flux density has a slightly peaked spectrum around 1 GHz. The kpc

scale radio image indicates a core-jet to northwest. The 15 GHz MOJAVE images revealed overall core-jets aligning with the kpc scale jet. The VLBA features are complex, with the first part: the east-end core-jet with diffuse ring emission widely around the jet within 5 mas, and the second part: a possible secondary ‘core’-jet like feature beyond 5 mas in the northwest. We measured the secondary ‘core’ position with respect to the primary core from the MOJAVE data, find that the angular distance is stable with 6.0 ± 0.5 mas in the past 17 years. The source was suggested to be a BBH system by Britzen et al. (2012), for its ring-like feature around the primary core-jet. We have a different view that the secondary BH might be locating at 6 mas northwest of the primary core, in this scenario, the ring-like feature may be resulted from a kind of reflection of the primary jets by the accretion disk of the secondary BH, more detailed modelling will be giving in the future.

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